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Identification of the bottlenecks in the non-production conveyor system using a simulation model

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Abstract: The performance of industrial systems is influenced by external factors, such as supply chain disruptions. The system usually cannot influence them much and must actively adapt to those external factors. On the other hand, there are also internal factors such as process synchronization and communication or resource allocation, which are entirely within the control of the system. Communication and synchronization need to be continuously monitored and assessed for various standard and non-standard situations. For such complex problems, which usually cannot be solved in acceptable time and resources by simple or exact methods, simulation is suitable and often used. This study uses simulation models to identify bottlenecks and propose corrective measures in a conveyor system used for processing customer-returned goods. Two simulation tools, Tecnomatix Plant Simulation (TPS) from Siemens PLM Software and AnyLogic software from AnyLogic Company, were used to model the system and test potential optimizations. The analysis identified critical bottlenecks, allowing targeted interventions, such as increasing conveyor speeds and optimizing input rates, which led to significant improvements in throughput and operational efficiency. Furthermore, the study demonstrates how simulation results can guide decision-making in areas such as resource allocation, capacity planning, and maintenance scheduling. While TPS proved more effective for detailed bottleneck analysis, AnyLogic's multi-method capabilities highlight its suitability for hybrid applications. The findings underscore the value of simulation in optimizing complex systems and provide insights applicable to other industrial sectors, emphasizing the potential of emerging technologies such as digital twins and AI-enhanced models to drive further innovation.

1 Introduction

The industrial system and its efficiency can be influenced by internal and external factors. Internal factors such as process synchronization and resource allocation are crucial for optimizing system performance, while external factors like supply chain disruptions, fluctuating customer demand, or material shortages impact efficiency. It is usually easier for a company manager to look for bottlenecks in the system caused by internal factors that can be more easily changed. Bottlenecks can be found in both production and non-production systems. In both systems, a bottleneck may be a machine with a low process speed or a long process time [1]. Weaknesses may include a logistics area with a limited flow rate causing congestion, the longest process time, the process with the lowest production line capacity, or delays in delivery to other parts of the system caused by repairs and maintenance of parts. For manufacturing systems, products or parts with the longest processing times, lowest speeds, or highest process requirements are usually the main bottlenecks [2]. A bottleneck may also arise on the human resources side, where there are few or insufficiently qualified workers. Bottlenecks arise when a particular process slows down overall operations. Identifying and mitigating bottlenecks improves efficiency by optimizing process flow and resource utilization. Several methods and techniques can be used to find bottlenecks, ranging from soft tools such as effective communication to sophisticated tools such as optimization [3] or simulation models [4]. Efficient communication and synchronization across system components is important as it significantly reduces downtime and enhances productivity. Simulation can help managers visualize and test coordination improvements without disrupting real operations. Properly aligned workflows ensure that conveyor processes operate smoothly, minimizing bottlenecks [1].

Simulation models are often used to reproduce a real system with its dynamic processes in a computer model. The main reason for using computer simulation in the analysis of managerial problems is the impossibility of using standard analytical tools due to complexity of real processes. The main task is to find knowledge that is applicable in the real system. In a broader sense, simulation can be understood as the preparation, implementation and evaluation of concrete experiments with a simulation model [5]. Simulation is a suitable method for the analysis of large-scale production and non-production systems that cannot be investigated using conventional analytical tools and their direct observation is not possible or would be very expensive in terms of time and money. The method is used in industrial environments as well as by researchers. As Kovbasiuk et al. [6] mentioned, the benefits of simulation include reducing investment risk, minimizing waste, improving efficiency, reducing energy consumption and even increasing worker health. Simulation can be used in the phase of operation of an existing system, in the planning of modifications to this system and in the phase of designing a completely new system. Simulations can be used to find bottlenecks in existing systems, to determine the use of workers and machines, or to test the system's response to extreme situations [7]. When designing modifications, it is possible to create different scenarios based on the results of the experiments carried out and by comparing them, it is possible to select and implement the most effective modifications to the system relatively quickly and easily [5]. When using a simulation model for the design of new systems, it is possible to eliminate the emergence of bottlenecks in the systems, to determine the response of the systems to extreme situations and to design a system specifically adapted to the process to be operated in it [8]. The great advantage of simulation is that it does not directly interfere with the running system. The simulation model considers only the factors that affect the operation and response of the system, so that it can reliably represent the system's response to real or hypothetical situations, and the results obtained lead to the design of meaningful measures to improve the system's efficiency [9].

Models can be created in different types of software, depending on the problem being modelled and the time variations involved in running the simulation [9]. There are many simulation models available, and the choice depends on the type of problem to be solved. Simulation models are divided into deterministic (the input and output variables remain constant) and stochastic (at least one of the input or output variables is determined by probability). Both of these categories can be static (time is disregarded) or dynamic (time-dependent interactions among variables are considered). Dynamic models in both cases are further divided into continuous (they rely on differential equations and attempt to measure changes in the system continuously over time due to control) and discrete (they react immediately to specific discrete events) [10]. If no time sequences are needed, only the application of Monte Carlo simulation could be effective, especially for iterative evaluation of a deterministic model. Monte Carlo simulation is associated with the systems affected by randomness when several different scenarios are randomly generated to obtain the probability description of the selected results [5]. Monte Carlo simulation repeats a lot of random experiments to find out the possible outcomes. But real simulation is usually made via discrete event simulation model or continuous simulation. Discrete event simulation (DES) is suitable for dynamic, stochastic systems that change in a discrete manner [11]. DES is common for models of economic and business processes, such as production and manufacturing systems [6-8,12-19] call centers or emergency medical services [20] or different scenarios and company strategies [8]. The detailed distribution of the simulation models is shown in Figure 1.

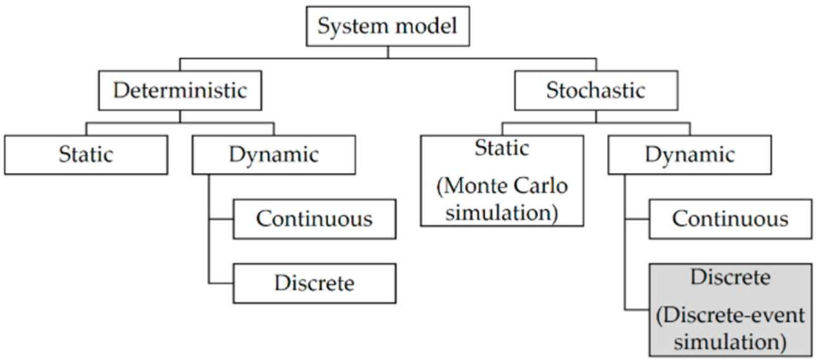

Figure 1 Diagram of simulation model types [10]

There are many applications or software for creating simulation models today. According to Captera.com [13], there are dozens of options for choosing the right program. Some of the most commonly used simulation programs within DES include AnyLogic, Arena, FlexSim, Plant Simulation, Simio, SIMUL8 or Witness. Kovbasiuk et al. [6] tested six DES packages – Arena, Anylogic, FlexSim, SIMUL8, TPS and WITNESS – all of the selected simulation software packages are aimed at analyzing the bottleneck processes, exploring possible “what-if” scenarios, providing “as-is” models, improving the existing systems and they are decision-making tools for enterprises. They concluded that TPS and FlexSim can be taken as the best covering all 11 simulation approaches such as 3D imaging, Agent-Based Modelling or stochastic and dynamic modelling. AnyLogic as the second tool in this comparison covers 10 simulation approaches as it does not have an industry specific database. Yakovlev et al. [21] used the AnyLogic software platform to build a complex simulation model of the conveyor line based on the discrete-event and two agent-based models. As a result of the simulation, the optimal number of pallets and the optimal batch size of products were determined. AnyLogic was also used to simulate and optimize the coal mine production logistics system [26]. TPS was used e.g. in a case study [23] to present the possibilities of this software for simulation of production and logistics processes, identification of bottlenecks in the production process and experiments leading to increased factory performance. Ashrafian et al. [24] used FlexSim software to optimize the operation of a fully automated modular conveyor system in a large-scale warehouse. A full-scale 3D DES model of the system was built and time-dependent statistical models were carefully designed and implemented in the model in order to capture the randomness and complex dynamics of the operation. The application of simulation program SIMUL8 to the analysis of production process in company Alteko, Inc. producing radial fans was presented by Fousek et al. [14]. The main purpose was to identify the bottleneck processes and to suggest the management the appropriate solution. Within the framework of the conveyor line control system development, a simulation model was created in Emulate3D [15] to verify the correct operation of the system control logic. During the simulation phase, errors in the logic were found and eliminated, resulting in an improvement in the operation of the system while reducing the time required to run the physical device.

Simulation also finds its application in the creation of a digital twin in Industry 4.0. For the robotics sector, RobotStudio has proven to be a simulator suitable for medium-performance computers with a wealth of functionality, which the user can also supplement with his own programming [16]. The simulator also enables the integration of the OPC UA communication protocol, which is enjoying growing acceptance in the industry. In the environment, a digital twin of the robotic laboratory system, mainly used for research, development and education, was created, consisting of several devices such as robotic arms, conveyors, automated warehouses and vision systems. RobotStudio is also suitable for selecting and optimizing the parameters of a robotic packaging process for one type of product. The main element of the research [7] was a computer simulation station based on the Picking PowerPac package. It was assumed that the products on the process line are generated pseudo-randomly, reflecting the actual working conditions. As a result of the tests performed, the optimal working speed of industrial robots and conveyors was obtained.

2 Methodology

The basic procedure for creating a simulation model has already been outlined by Banks et al. [25] in 12 steps from problem formulation, through data collection, model creation, model verification, validation, experiments with the model implementation of changes in a real system. This procedure is more or less still followed, or some steps are structured in more detail with respect to the nature of the system being modelled. Banksow et al. [5] mention these 8 steps: 1. Formulation of problems, 2. Test of the simulation-worthiness, 3. Formulation of targets, 4. Data collection and data analysis, 5. Modeling, 6. Execute simulation runs, 7. Result analysis and result interpretation, 8. Documentation. Sharma [19] described the process in 11 steps: 1. problem formulation, 2. objectives settings, 3. decision about the type of the model, 4. conceptualization of the problem, 5. data collection, 6. software selection, 7. building a simulation model, 8. verification and validation of the model, 9. model testing and change of inputs, 10. results description, 11. documents or reports creation. Finally, Saderova and Ambrisko [23] put all the methodology steps into the scheme (see Figure 2) which we followed in this paper.

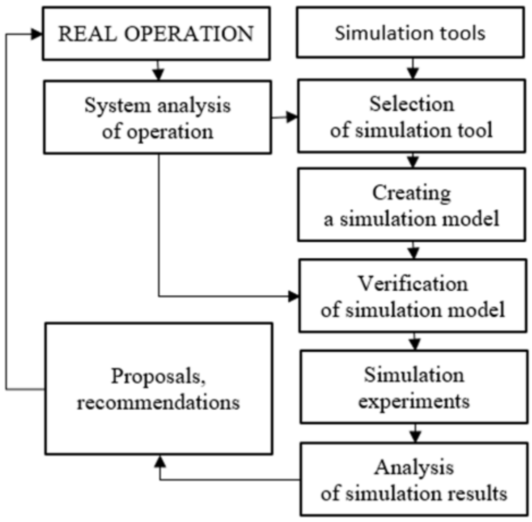

Figure 2 Steps of methodology based on [23]

System analysis (problem and targets formulation) was made by the client, which also gave us a data and the complete description of the system. The main task was to create a simulation model to find out all bottlenecks and to test the changes in the input rates and conveyors speed.

The choice of simulation tool (software selection) was influenced by our capabilities and the needs of the modelled system. As the objective was also to compare the two selected simulation programs, we decided for Tecnomatic Plant Simulation [26] and AnyLogic [27], which were available for download and testing (student version) without payment.

The following chapters contain further steps, i.e. in particular the description of the system, the creation of the model and its verification, simulation experiments, comparison of results and recommendations for real system changes. Key metrics used in simulation models are based on the statistics taken from several runs with confidence intervals to estimate the precision of the metrics such as throughput rate, utilization rates or blocking and idle times. Finally, we compare the advantages and disadvantages of the chosen simulation software.

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3 Problem formulation and description

The described methodology was used to find the bottlenecks in the conveyor network, correct them and subsequently increase the efficiency of the system. Another objective is to compare the functionality and evaluate the use and results obtained with two selected freely available versions of simulation tools. The diagram of the conveyor system and its components are shown in Figure 3. For better clarity, the names in the diagram have been abbreviated: So denotes Source, St denotes Storage, C_ denotes Conveyor, M_ denotes Machine and W_ denotes Workplace. Each element is also assigned a numerical designation within the network for better orientation in identifying bottlenecks.

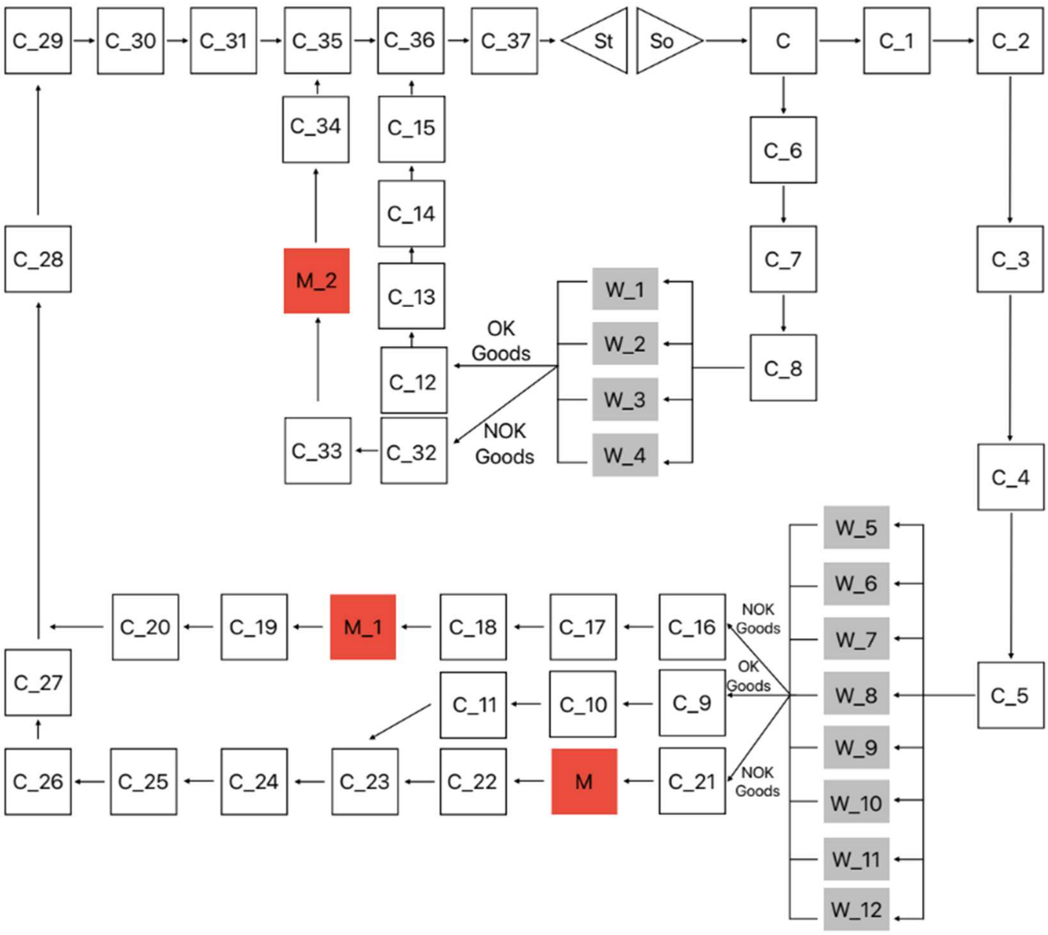

Figure 3 Diagram of the conveyor system (conceptualization of the problem)

The existing system under study consists of a set of roller conveyors connected to each other. The conveyors are used to transport parcels of returned goods. Within the conveyor network, there is a large main branch and a smaller secondary branch through which the goods can pass. In each branch there is a workstation with entry control staff that decides on the further progress of the returned goods. If the goods are free from defects, they are passed onto the violet conveyor and go to the bin where they await further processing. If the inspection station assesses that the returned goods are not free of defects, they pass them to the yellow or green conveyor. Each of the conveyors passes through machines that clean the returned goods. After passing through these machines, the goods go back into the storage bin where they await further processing. The source of the goods is the warehouse on the lower floors of the building, which is continuously stocked and has sufficient inventory to supply the system with packages for a full eight-hour shift. All conveyors are 640mm wide and the parcel size is 500x400x100mm. The individual conveyors consist of multiple parts that are driven by their own motors. Motor speeds range from 0.1 – 1.5 m/s. The speed of parcels entering the system is 30 pcs/min. The other parameters of the simulation model were set to the values shown in Table 1.

Table 1 Table with system input data

	Branches description	Usage by incoming inputs [%]	Workstation capacity [pcs/hr]	Number of workers/machines [pcs]	Total capacity [pcs/hr]	Speed [m/s]
Blue main branch	**Conveyor**	80	Transport of goods only		Transport of goods only	0.8
	Conveyor_1 - 4	80	Transport of goods only		Transport of goods only	0.1, 0.8, 0.4, 0.8
	Conveyor_5 (Workplace_5 - Workplace _12)	80	121	32	3872	0.56
Blue secondary branch	**Conveyor_6 - 7**	20	Transport of goods only		Transport of goods only	0.35, 0.55
	Conveyor_8 (Workplace_1 - Workplace _4)	20	90	16	1440	0.8
Violet main branch	**Conveyor_9 - 11**	10	Transport of goods only		Transport of goods only	0.8, 0.69, 0.69
	Violet secondary branch					
	Conveyor_12 - 15	2	Transport of goods only		Transport of goods only	0.8, 1.2, 0.8, 0.53
Yellow main branch	**Conveyor_16 - 18**	35	Transport of goods only		Transport of goods only	0.8, 0.8, 0.8
	Conveyor_19 (Machine1)	35	800	1	800	0.1
	Conveyor_20	35	Transport of goods only		Transport of goods only	0.33
Green main branch	**Conveyor_21**	35	Transport of goods only		Transport of goods only	0.8
	Conveyor_22 (Machine)	35	800	1	800	0.1
	Conveyor_23 - 31	35	Transport of goods only		Transport of goods only	0.1, 0.7, 0.8, 0.8, 0.6, 0.8, 0.8, 0.8, 0.8
Green secondary branch	**Conveyor_32**	18	Transport of goods only		Transport of goods only	0.8
	Conveyor_33 (Machine2)	18	800	1	800	0.8
	Conveyor_34	18	Transport of goods only		Transport of goods only	0.8
Green end conveyors	**Conveyor_35 - 37**	100	Transport of goods only		Transport of goods only	0.8, 1.5, 0.8

4 Simulation models

TPS is a 3D object-oriented program used for DES [26]. Machines, conveyors, people and embedded clicks to analysis tools are referred to as objects. The program can create digital twins containing manufacturing or non-manufacturing processes, robots, automation, systems containing material handling and workers. It is a tool suitable for simulating, evaluating and implementing advanced manufacturing techniques, equipment and operations to increase system flexibility. The program contains predefined objects and functions, but it also allows to write own methods or conditions necessary for the correct functioning of the system. The application is produced and distributed by the German company Siemens PLM Software, which has long been engaged in providing support and appropriate solutions in the field of innovation and optimization of business processes. The application can be obtained in various versions from paid professional versions to student free versions, which are limited by the number of objects used in the model being created. The program allows the use of tools such as bottleneck analysis, statistical reports, graphs or Sankey diagrams to evaluate the efficiency of the system or the suitability of proposed measures. Compared to AnyLogic, the simulation model does not stop the simulation run in case of system overload, but records the progress in statistics and distinguishes the time for which individual objects of the model are working, waiting for the arrival of new goods or are blocked by goods.

For the purposes of this paper, the Student version was used, which is limited to 80 placed objects, but is not otherwise functionally limited. The resulting model of the original conveyor system is shown in Figure 4.

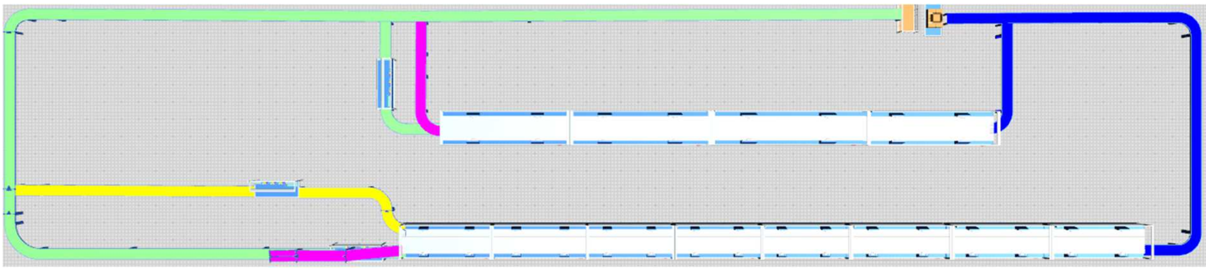

Figure 4 Digital twin of the analyzed conveyor system in TPS

To compare the functionality of the simulation programs, the same model was created in the aforementioned AnyLogic program, which is also available in different versions. For the purposes of this paper, the free version Personal Learning Edition was used, which is limited by the insertion of more sophisticated objects (only conveyors and simple workstations or machines can be inserted), but also by the length of the simulation run to 1 hour. Figure 5 shows a model of the original conveyor system in AnyLogic.

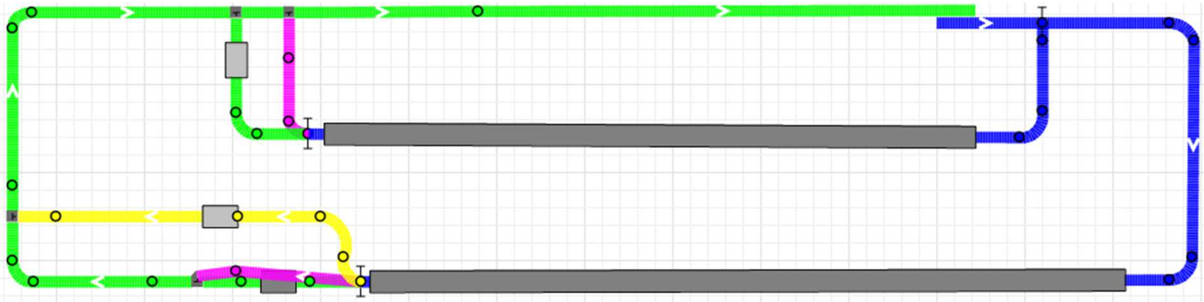

Figure 5 Digital twin of the analyzed conveyor system in AnyLogic

Due to limitations in simulation programs, the workplaces are modelled as stations and the input control personnel are not physically represented in the models. Parameters of the stations (speed and method of work, procedure for goods inspection) correspond to the input control workers in their settings. Verification of the functionality and effectiveness of the proposed measures was carried out only in TPS, as it allows for a simulation run of one shift.

5 Simulation

The simulation was always run for 30 runs of the length corresponding to one shift in TPS and for 1 hour in Anylogic in case no bottleneck was found in the shorter time. In the following subsections, the individual experiments and their results are presented.

5.1 *Identification of AnyLogic bottlenecks*

When setting the parameters specified in the problem formulation, the system crashed after 82 seconds of running the simulation in Anylogic and thus stopped running completely. In Figure 6, the red ellipse indicates the point of system collapse.

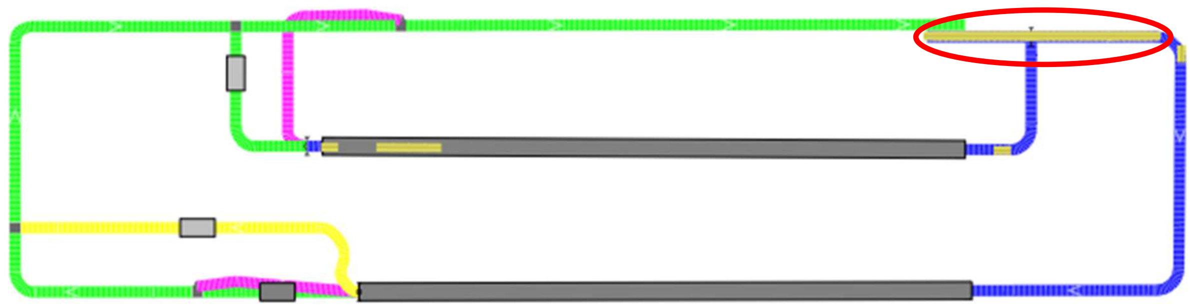

Figure 6 Identification of a bottleneck in AnyLogic

The program stopped running due to the fact that it was not possible to send more goods to the system. The bottleneck of the system is the first conveyor of the main branch (Conveyor_1), whose speed is 0.1 m/s, which was only able to send one package further into the system during the simulation run. It is not possible to restart such a stopped run, only to repeat the complete run. Thus, AnyLogic cannot identify multiple bottlenecks at once, because it stops the run on the first one found.

5.2 Identification of Tecnomatix Plant Simulation bottlenecks

With identical settings of the model parameters, TPS performed a simulation run of the entire shift without stopping. 6,762 returned packages entered the system, 5,400 packages passed through the main branch, 1,350 through the secondary branch and 6,672 packages were stored for further processing. In Figure 7, the red ellipse again highlights a bottleneck in the system. It is clear that the bottleneck will be on the blue main branch and will be either Source, Conveyor or Conveyor_1 (see Table 1), as the rest of the system is not overwhelmed.

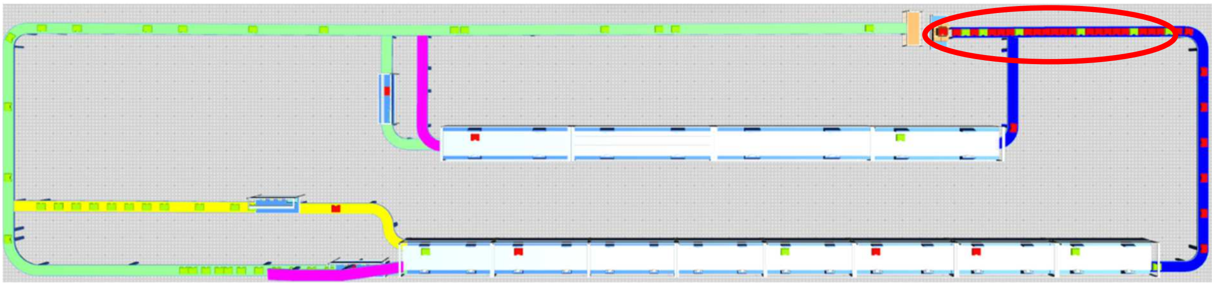

Figure 7 Identification of a bottleneck in TPS

In this situation, it is not possible to clearly say which of the mentioned parts is the bottleneck, so in addition to the simulation, TPS also records statistics. The most important fragment of the statistics record is shown in Table 2. In addition to the name of the object, the statistics contain data on what percentage of the working time the object worked, what percentage waited for the arrival of the next goods to be processed, and what percentage of the working time was blocked by goods that could not be passed on to the next object. Finally, it combines these 3 data into a diagram, where the work time is represented in green, the waiting time in grey and the blocking time by goods in orange. The statistics also contain other data such as rebuilds, power on/off and faults, but these have no input data in the model and therefore cannot take values other than 0. The statistics show that Source and Conveyor are blocked most of the time because the following Conveyor_1 link is too slow, even though it is running at full performance. The simulation results were the same in all 30 cases.

Table 2 Statistics for potential bottlenecks in the blue main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Source	0.00%	0.00%	0.13%	99.87%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_6	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor	15.71%	0.00%	0.00%	84.29%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

6 Newly proposed scenarios

In the following subsections, individual proposals for eliminating the identified bottlenecks in the system are presented. The individual proposals are considered both in terms of simulation capabilities and applicability in practice. As a possible remedial action, the sponsor has allowed the replacement of the conveyor motors with new ones with a speed of 0.8 m/s and the simulation has been able to identify the motor that needs to be replaced. The corrective actions are now only verified in TPS to better see the impact of the changes on the entire system throughout the working time.

6.1 Replacing motors of selected conveyors

The simulation runs showed that there is clearly 1 bottleneck in the system (Conveyor_1) for which the motor was replaced with a new one with a speed of 0.8 m/s. Newly 13,500 packages with returned goods entered the system, 10,798 packages passed through the main branch, 2,700 through the secondary branch and 13,350 packages were stored for further processing. When the motors were replaced, the speed of the parcel through the conveyor system was increased and the quantity processed was also increased. After the motor replacement, new bottlenecks appeared, see Figure 8, where the system is after the application of the corrective measure and the bottlenecks are marked with red ellipses.

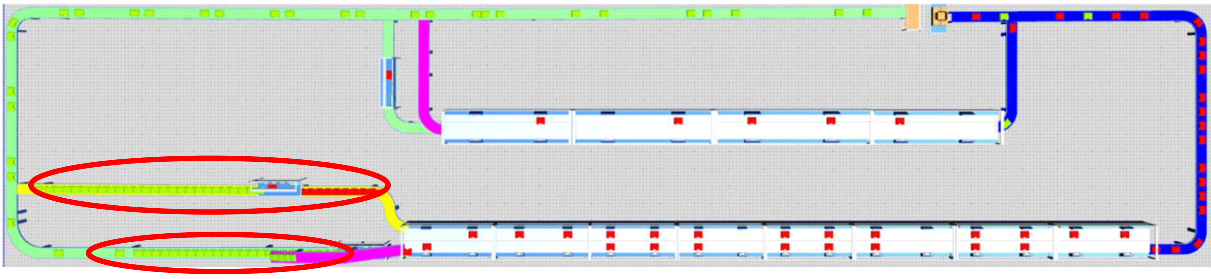

Figure 8 Newly identified bottlenecks

Potential bottlenecks in the yellow main branch are Conveyor_18, Machine1 or Conveyor_19 (see Table 1). The statistics (see Table 3) show that the bottleneck is Conveyor_19, because the previous section Machine1 is blocked almost 20% of the working time by goods it has already processed but cannot send on.

Table 3 Statistics for potential bottlenecks in the yellow main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Conveyor_19	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	79.32%	0.00%	1.13%	19.55%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Potential bottlenecks in the green branch are Machine, Conveyor_22, or Conveyor_23 (see Table 1). The statistics based on the results of all simulation runs (see Table 4) show that the bottleneck is Conveyor_22, because the previous article Machine is blocked more than 50% of the working time by goods that it has already processed but cannot send on.

Table 4 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	47.94%	0.00%	0.46%	51.60%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_22	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_23	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Conveyor_22 and Conveyor_23 are 1 conveyor in the real system, which must be divided into 2 fragments in the model for the reason that the correct transfer of goods between the green and violet main branch occurs in the program. For this reason, it will be proposed to replace the motors of both conveyors (both parts in the real system).

Replacing motors on Conveyor_19 and Conveyor_22 + Conveyor_23

The simulation runs showed that there are 2 additional bottlenecks in the system (Conveyor_19 and Conveyor_22 + Conveyor_23) for which the motors were replaced with new ones with a speed of 0.8 m/s. Newly 13500 returned packages entered the system, 10,798 packages passed through the main branch, 2,700 through the secondary branch and 13,417 packages were stored for further processing. The replacement of the motors resulted in a faster passage of the parcel through the conveyor system, not an increase in the quantity of parcels processed, only an increase of 67 parcels stored for further processing. Figure 9 shows the system after the corrective actions have been implemented.

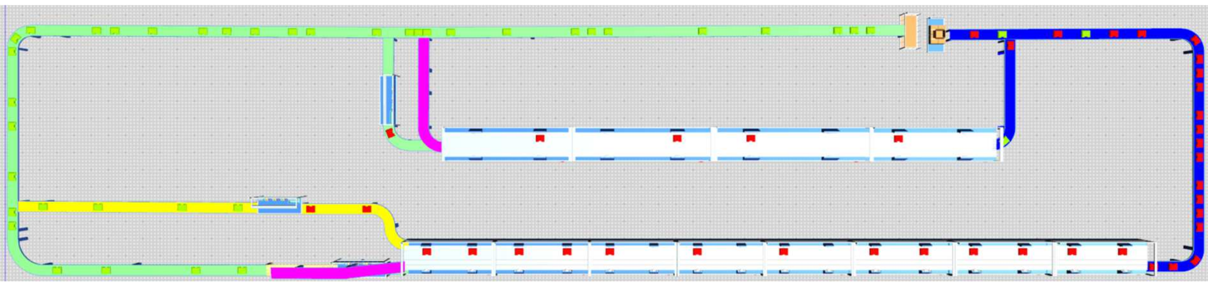

Figure 9 The system after the implementation of the second wave of corrective actions

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At first glance, there are no more bottlenecks in the system. The statistics no longer show any objects that are blocked by goods that cannot be sent on. Table 5 shows a fragment of the statistics, which shows that machines for repairing returned goods have to wait for a relatively large part of the working time for the goods to arrive.

Table 5 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	63.59%	0.00%	36.41%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	63.97%	0.00%	36.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	31.53%	0.00%	68.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Given the lower use of working machines, another proposed action is to increase the speed of entering packages into the system, which should increase the amount of processed packages and thus the use of working time.

6.2 *Changing the intensity of parcel entry into the system (input rate)*

The speed of the system will be gradually increased by 5 pcs/min until the system is stable and no bottlenecks occur. If a speed is found at which the system is not stable and new bottlenecks are created, a new speed change will be performed using sensitivity analyses.

Input rate 35 pcs/min

The new speed is set to 35 pcs/min. 15,790 packages with returned goods entered the system, 12,630 packages passed through the main branch, 3,157 through the secondary branch and 15394 packages were stored for further processing.

There are no newly generated bottlenecks visible in the system and the statistics did not show any newly generated bottlenecks. Table 6 again shows the statistics for the repair machine, the new machine utilization increased to more than 74% for machines on the main branch and to more than 36% for machines on the secondary branch.

Table 6 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	74.15%	0.00%	25.85%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	74.65%	0.00%	25.35%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	36.87%	0.00%	63.13%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Input rate 40 pcs/min and 45 pcs/min

The new speed is set to 40 pcs/min. The system has now received 18,000 returned parcels, 14,390 parcels have passed through the main branch, 3,600 through the secondary branch and 17,889 parcels have been stored for further processing. The system is still stable, there are no newly generated bottlenecks and the statistics have not shown any newly generated bottlenecks. Table 7 again shows the statistics for the repair machine, the new machine utilization increased to 85% for the machine on the yellow branch, more than 84% for the machine on the green branch and more than 42% for the machine on the secondary branch.

Table 7 Statistics for inefficiently used machines

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Machine	84.48%	0.00%	15.52%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	85.00%	0.00%	15.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine2	42.03%	0.00%	57.97%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

For the next 30 simulation runs, the new speed is set to 45 pcs/min. 20,256 returned parcels entered the system, 16,202 parcels passed through the main branch, 4,050 through the secondary branch and 20,127 parcels were stored for further processing. The system is still stable, no newly generated bottlenecks are evident and the statistics did not show any newly generated bottlenecks. The new machine utilization increased to over 95% for the machine on the yellow branch, over 94% for the machine on the green branch and over 47% for the machine on the secondary branch.

Input rate 50 pcs/min

The new model is set to a speed of 50 pcs/min. Newly 21,256 packages with returned goods entered the system, 16,995 packages passed through the main branch, 4249 through the secondary branch and 21,067 packages were stored for further processing. Table 8 shows the results - it is clear that the system is no longer stable (blocked objects) and new bottlenecks have appeared.

Table 8 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Source	0.00%	0.00%	9.14%	90.86%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor	53.54%	0.00%	0.00%	46.46%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	79.96%	0.00%	0.19%	19.85%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_5	98.61%	0.00%	0.21%	1.18%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_6	98.67%	0.00%	0.21%	1.12%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_7	98.93%	0.00%	0.21%	0.86%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_8	98.83%	0.00%	0.22%	0.95%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_9	99.02%	0.00%	0.22%	0.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_10	98.85%	0.00%	0.23%	0.93%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_11	98.68%	0.00%	0.24%	1.08%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_12	99.02%	0.00%	0.24%	0.74%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_16	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_17	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	99.64%	0.00%	0.36%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

The statistics show that the bottleneck is one of the Conveyor_16 - Conveyor_18 (see Table 1), because the workstations are blocked by goods for a small part of the working time. There is no way to change this situation as all conveyors are already at the maximum speed of the new motors of 0.8 m/s.

6.3 *Sensitivity analysis of input rate*

The maximum tolerable value for the input rate of packets into the system is between <45;50) pcs/min. To find a specific value, a sensitivity analysis will be performed where the intensity will be increased from 45 pcs/min one piece at a time and 30 runs of simulation will be performed again with the newly found value. The system will be subjected to an input rate of 46 pcs/min.

Input rate 46 pcs/min and 47 pcs/min

The new speed is set to 46 pcs/min. 20,770 packages with returned goods entered the system, 16,631 packages passed through the main branch, 41,53 through the secondary branch and 20633 packages were stored for further processing. Figure 10 shows the system after the introduction of the new action. The system is still stable, there are no newly generated bottlenecks and the statistics have not shown any newly generated bottlenecks. Figure 20 again shows the statistics for the repair machine, the new machine utilization on the main branch is close to 100% and 49% for the machine on the minor branch.

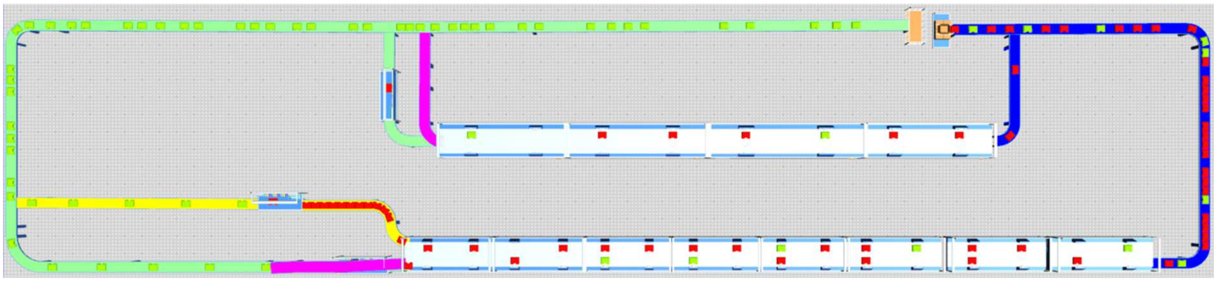

Figure 10 System after increasing the rate of parcels entering the system to 46 pcs/min

The new speed is set to 47 pcs/min. 21,144 packages with returned goods entered the system, 16,912 packages passed through the main branch, 4,228 through the secondary branch and 20,990 packages were stored for further processing. Figure 11 shows the system after the introduction of the new measure. It is very clear from the figure that the system is no longer stable and new bottlenecks have emerged.

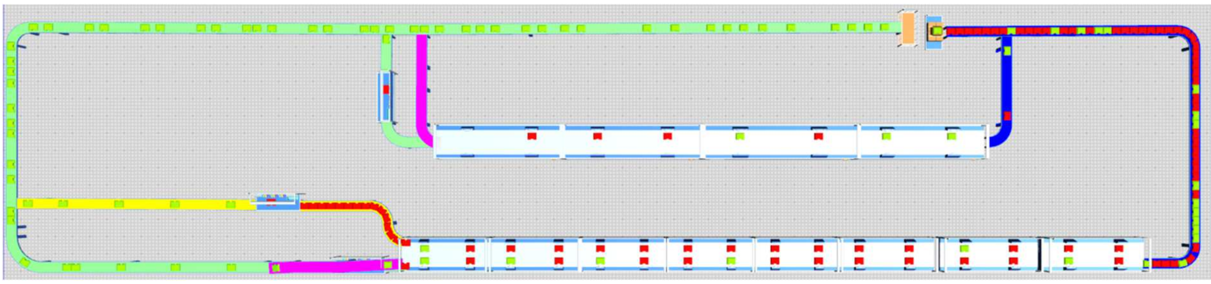

Figure 11 System after increasing the intensity of parcels entering the system to 50 pcs/min

The statistics (see Table 9) show that the bottleneck is one of the Conveyor_16 - Conveyor_18 (see Table 1), because the workstations are blocked by goods for a small part of the working time. There is no way to change this situation as all conveyors are already at a maximum speed of 0.8 m/s. Based on the above simulation experimental results, the maximum allowable value of packet intensity entering the system is 46 pcs/min.

Table 9 Statistics for potential bottlenecks in the green main branch

Object	Working	Set-up	Waiting	Blocked	Powering up/down	Failed	Stopped	Paused	Unplanned	Portion
Conveyor	81.28%	0.00%	0.00%	18.72%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_1	88.76%	0.00%	2.30%	8.94%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_2	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_3	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_4	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_5	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_5	99.20%	0.00%	0.22%	0.58%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_6	99.05%	0.00%	0.22%	0.73%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_7	99.14%	0.00%	0.22%	0.64%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_8	99.00%	0.00%	0.24%	0.76%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_9	99.10%	0.00%	0.23%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_10	99.11%	0.00%	0.25%	0.64%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_11	99.07%	0.00%	0.27%	0.66%	0.00%	0.00%	0.00%	0.00%	0.00%	
Workplace_12	99.07%	0.00%	0.26%	0.67%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_16	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_17	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Conveyor_18	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	
Machine1	99.35%	0.00%	0.65%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

7 Results comparison

Based on experiments with simulation models created in AnyLogic and TPS to test potential improvements and efficiency of the conveyor network, a total of 3 bottlenecks were identified. These were the conveyors with the slowest motors. The primary proposed corrective action to eliminate the bottlenecks is to replace the old conveyor motors with new ones with a speed of 0.8 m/s. Key metrics used to assess the performance of the conveyor system include throughput rate, utilization rates, blocking and idle times, and input rate stability. The proposed changes were tested under conditions identical to the original system, and the simulation results were used to derive additional suggestions for increasing the efficiency of the conveyor network system, such as increasing the speed of packages entering the system. Due to the lower utilization of working time for the repair machines, system stability tests were performed for the new values of the intensities of the packages entering the system. The quantities of returned parcels in pieces for the main model fragments are shown in Table 10.

Table 10 Results of the experiments

Model	Input	Main branch	Secondary branch	Output
Unmodified digital twin	6,762	5,400	1,350	6,672
Corrective action 1	13,500	10,798	2,700	13,350
Corrective action 2	13,500	10,798	2,700	13,417
Input rate 35 pcs/min	15,790	12,630	3,157	15,394
Input rate 40 pcs/min	18,000	14,390	3,600	17,889
Input rate 45 pcs/min	20,256	16,202	4,050	20,127
Input rate 50 pcs/min	21,256	16,995	4,249	21,067
Input rate 46 pcs/min	20,770	16,631	4,153	20,633
Input rate 47 pcs/min	21,444	16,912	4,228	20,990

The throughput rate increased significantly following the simulation interventions, with the system stabilizing at a maximum input rate of 46 pcs/min. Compared to the original setting, an increase of 16 pcs/min has been made.

Machine utilization increased by more than 30% on the main branch and almost 17% on the secondary branch.

In addition to improving the state of the system, the aim was also to compare the AnyLogic and TPS simulation programs and several differences in the functionality of both were found. The biggest difference is in the functionality of the freely available versions of the program, with TPS being limited by the number of objects placed and AnyLogic, on the other hand, being limited by the length of the simulation run in addition to the insertion of different types of objects. Another major difference is in the way the programs work, where AnyLogic terminates the run at the first bottleneck found in the system, while TPS terminates the run only after a set time is reached and any bottlenecks can be identified quite well from the generated statistics.

Currently, the model contains machines that are fault-free and their maintenance is carried out off-shift. It is also considered that the goods returned by customers are only with minor defects that can be corrected by the repair machine. In the future, it would be useful to include the failure rate of machines in the model, to define the rejection rate for sorted goods or to determine the financial and energy intensity for individual objects in order to obtain even better results. In the case of a full version, it would also be useful to include the input inspection staff in the model and to create shift schedules for them. It would also be useful to consider changing the probabilities for the distribution of goods at the first crossroads. The distribution currently used corresponds to the setup of that system, but changing it to, for example, 75:25 or 70:30 could further increase the efficiency of the conveyor system once the new measures are in place. However, such a change is an intervention that is not yet foreseen by the contracting authority in the future development of the system and thus has not been considered at present.

8 Conclusion

This study highlights the critical role of simulation models in identifying and addressing inefficiencies within conveyor systems. By employing targeted strategic adjustments, such as replacing low-performing conveyor motors and optimizing input rates, the system's throughput increased significantly while maintaining operational stability. These interventions underscore the potential for simulation to guide decision-making, enabling managers to prioritize resources effectively, plan maintenance schedules, and test scenarios for enhanced resilience.

The main goal was to find all the bottlenecks in the system with conveyors and test the effect of the speed changes on the output of the system. At the same time, the aim was also to compare the capabilities of 2 freely available simulation tools - TPS and AnyLogic. According to the rules and system data provided by the client, a simulation model was created in both of these programs: TPS and AnyLogic. Due to the limitations of AnyLogic, which stops the simulation run when the first bottleneck is detected, preventing a complete analysis of the entire shift, we decided to perform all further experiments using the more robust TPS model. Through complex simulation runs, three significant bottlenecks were identified that hindered the throughput of the system. To mitigate these constraints, a series of experiments were conducted by varying the input speed and adjusting the conveyor speed in the target segments of the system. The results of these scenario tests allowed us to evaluate different configurations and determine the optimal operating parameters that effectively minimized or eliminated the bottlenecks. The throughput rate increased significantly following the simulation interventions, with the system stabilizing at a maximum input rate of 46 pcs/min. Machine and workstation utilization also improved, particularly for critical machines, which operated near full capacity. Blocking times decreased, signaling smoother process flow and enhanced synchronization among system components. This study underscores the importance of using advanced simulation tools that allow for system analysis to identify and resolve complex bottlenecks. The findings provide practical insights into the dynamic behavior of conveyor systems and highlight the potential for improving operational efficiency through strategic adjustments. This approach can serve as a valuable framework for similar analyses in other non-production conveyor applications, contributing to the development of more resilient and efficient material handling processes. The broader significance of these findings extends beyond conveyor systems to other industrial applications, where similar methodologies can be leveraged to optimize workflows, reduce downtime, and improve overall productivity.

For the simulation tools' comparison, we can conclude (similarly as in [6]) that both tools have their strengths and are best suited for different applications. AnyLogic is ideal for projects requiring a blend of methodologies (e.g., combining agent-based and discrete event simulations) and those needing flexible output visualization. Its graphical interface and drag-and-drop functionality make it easier to create models without extensive coding and it also provides clear, detailed, and customizable visualization options for simulation results. As one main disadvantage we see the fact that it can stop simulation runs when the first bottleneck is detected, which can hinder comprehensive long-term analysis. The other problem lies in the model creation: while basic modeling is user-friendly, mastering more complex functionalities and custom Java coding requires significant learning time.

TPS excels in detailed manufacturing and logistics systems with built-in tools for complex conveyor and production line modeling. This tool is suitable for this type of problem offering built-in tools for detailed analysis, such as bottleneck detection and throughput statistics, provide clear insights into system performance. Unlike AnyLogic, Plant Simulation can run through the entire shift or time period to show complete results for long-term analysis. The disadvantages of using this software include e.g. that the tool's extensive capabilities can be more challenging to learn, especially for users unfamiliar with simulation software, its coding capabilities are not as flexible or extensive as AnyLogic's Java-based system and simulating very detailed models can be resource-intensive and may require powerful hardware.

The biggest advantage of these type of simulation models lies in the ability to test system changes only within the model without having to incorporate them into the real process. This research demonstrates the value of integrating simulation-based approaches into strategic planning, fostering data-driven decisions that drive efficiency and competitiveness. Analyzing key performance metrics such as throughput rate, utilization rates, blocking and idle times, and input rate stability provides valuable insights into conveyor system efficiency. These metrics help identify bottlenecks, underutilized resources, and workflow inefficiencies, enabling informed decisions on equipment upgrades, process adjustments, and maintenance scheduling. By leveraging this data, organizations can optimize operations, enhance productivity, and proactively address potential issues, leading to improved overall performance.

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